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Statistical Signal Processing for Demining: Modeling and Experimental Validation

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13. ABSTRACT (Maximum 200 words)
Under the support provided by ARO in the form of a MURI for Humanitiarian demining, successful techniques for discriminating between mines and anthropic clutter have been developed using a statistical signal processing approach. In order to determine whether these algorithms have wider application than the relatively high-metallic content mines used in other experiments, the Joint UXO Coordination Office (JUXOCO) was interested in augmenting the work begun under the MURI. JUXOCO is sponsoring a series of experiments designed to establish a performance baseline for metallic mine detectors. This baseline will be used to measure the potential improvements in performance offered by advanced signal processing algorithms. One goal of the work funded under this grant was to develop statistical algorithms for processing data previously collected with the GEM-3 and PSS-12. A second goal was to develop phenomenological models to explore (1) the void effect observed under a previous grant and (2) the Wichmann radar. This report provides a summary of the results obtained during the course of this study and a summary.

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(1) List of Manuscripts

- Gao, P. and Collins, L. "A 2-dimensional Generalized Likelihood Ratio Test for Landmine Detection", Signal Processing 80 (2000), 1669-1686.
- Gao, P. and Collins, L. "A theoretical performance analysis and simulation of time-domain EMI sensor data for land mine detection", IEEE Transactions on Geoscience and Remote Sensing, Vol. 38, No. 4., July, 2000, 2042-2055.
- Gao, P., Collins, L. M., Garber, P., Geng, N. and Carin, L., "Classification of landmine-like metal targets using wideband electromagnetic induction", IEEE Trans. Geoscience and Remote Sensing, Vol. 38, No. 3, May, 2000, 1352-1361.
- Collins, L. and Gao, P. "Improved detection of low-metal mines", Proc 2000 IEEE International Geoscience and Remote Sensing Symposium, Honolulu, Hawaii, July, 2000.
- Collins, L., Gao, P., Tantum, S., Makowsky, L., Cary, J., Reidy, D., Moulton, J., and Weaver, D., "Signal Processing for Low Metal Mine Detection and Identification: Results from a Blind Field Test", EUROEM 2000, Edinburgh, Scotland, June, 2000.
- Gao, P. and Collins, L., "Time-Domain Metal Detector and GPR Data Processing and Fusion for Landmine Detection", Detection and Remediation Technologies for Mines and Minelike Targets V Conference, 2000 International Symposium on Aerospace/Defense Sensing and Controls, Orlando, Florida, April, 2000.
- Gao, P. and Collins, L., "Bayesian Optimal Classification of Metallic Objects: A Comparison of Time-Domain and Frequency-Domain EMI Performance", Detection and Remediation Technologies for Mines and Minelike Targets V Conference, 2000 International Symposium on Aerospace/Defense Sensing and Controls, Orlando, Florida, April, 2000.
- Collins, L., Tantum, S., Gao, P., Weaver, R., Reidy, D., Makowsky, L., Cary, J., Moulton, J., "Improving Detection of Low-Metallic Content Landmines Using EMI Data" Detection and Remediation Technologies for Mines and Minelike Targets V Conference, 2000 International Symposium on Aerospace/Defense Sensing and Controls, Orlando, Florida, April, 2000.
- J.Q. He, T..J Yu, N. Geng and L. Carin, "Method of moments analysis of electromagnetic scattering from a general three-dimensional dielectric target embedded in a layered medium," Radio Science, vol. 35, pp. 305-313, Mar-Apr 2000.
- T.J. Yu and L. Carin, "On the inductive response of a conducting void embedded in a soil medium," to appear in IEEE Trans. Geoscience & Remote Sensing, May 2000.

(2) Scientific personnel

- Leslie M. Collins, Ph.D.
- Lawrence Carin, Ph.D.
- Ping Gao, Ph.D. (graduate student)

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- Haitao Yu , Ph.D. (post-doc)
- Xianyang Zhu, Ph.D. (post-doc)
- Debbie Schoefield, M.S. (research assistant)

1 Ph.D. was conferred during the course of this year (Ping Gao).

(3) Reports of Inventions

None

(4) Scientific progress and accomplishments

Task I. Statistical signal processing

Work completed: Statistical algorithms have been developed for the GEM-3 which utilize (1) the energy at the center location (baseline) (2) the spatial energy pattern, (3) the frequency-domain signature measured at the center point, (4) a combination of (2) and (3). Substantial improvements in performance over the baseline were obtained. An algorithm that also considered the frequency-domain signature as a function of space was developed, but the performance was not substantially above baseline. The algorithms were trained on data obtained in the calibration lanes. The frequency-domain algorithms used all of the frequency-domain data, they did not utilized features extracted from the data. Power point files illustrating the performance improvements have been supplied to JUXOCO.

A second algorithm was developed termed the "nGLRT". It was more robust to variability in the signature as a function of depth. Its performance was compared using a single point, all of the spatial data, and when fused with the spatial data from the PSS12. The results from this algorithm were superior to those obtained previously. Power point files illustrating the performance improvements have been supplied to JUXOCO and the results were presented at SPIE and the UXO/Countermine Forum.

A statistical algorithm has been developed for the PSS-12 that utilizes features extracted from the spatial energy pattern of the data obtained from test pin 3. Features were used as opposed to the raw energy data because data was only acquired in the calibration lane once, so no statistical characterization was possible. Also, the overall level of the signals in the "blanks" of the cal lane were quite different from the baseline levels of signals in the main grid. Thus, features extracted from the data that were not dependent on the absolute level were utilized. The performance of this algorithm substantially improved performance with respect to the baseline. Power point files illustrating the performance improvements have been supplied to JUXOCO.

In cooperation with Lloyd Riggs, the differential amplifier data was downloaded from the JUXOCO web site and the pertinent information was extracted. In general, the quality of the data appears to be substantially lower than the energy data obtained from test pin 3. The spatial energy patterns was noisier and less consistent across targets. ROCs did not obtain the performance level observed for the energy data obtained from test pin 3.

The receive coil data from the PSS12 taken by Lloyd Riggs was obtained from the web site. Three algorithms were developed. One operated on a single decay rate extracted from the data. The other operated on the entire signal and integrated over the uncertainty in the decay rate. The third fused the output of one of the first two algorithms with the spatial data, since decay curves were only measured at the center point. Neither of the first two algorithms attained the performance level of that observed with the GEM3, however performance was better when the entire signal was utilized. Fusing the output of either of the first two algorithms with the spatial data improved performance. Power point files illustrating the performance improvements have been supplied to JUXOCO, and a paper has been written describing the results.

Task II. Modeling the void effect and incorporating into signal processing

Work completed: The rigorous method of moments (MoM) and the approximate extended-Born technique have been used to model the three-dimensional problem of a lossless dielectric object situated in a lossy dielectric medium (soil). Specifically, the response of the GEM-3 to the presence of a conducting void (absence of conductivity) has been modeled. The MoM results were used to calibrate the accuracy of the approximate extended-Born solution. The model indicates that a conducting void can be detected via an EMI sensor operating at the appropriate frequencies. The electromagnetic character of the void was dependent on the target and soil properties as well as on the frequency of operation. The model also indicates that by adding water to the soil, the contrast can be enhanced, thus increasing the target signature.

Data was collected over simple dielectric targets and model predictions and measured data (GEM3) were shown to agree. Future work involves modeling the response of a mine as opposed to a simple dielectric cylinder and comparing the results to measured data.

A paper describing the model has been written and provided to JUXOCO.

Task III. PSS12 real-time algorithm development

Work completed:

Data was collected with the system in the main grid of the JUXOCO test site (see task 1) and an algorithm was developed. This algorithm has been implemented in LabView and can be tested in a real-time environment. However, Duke's PSS12 did not provide similar outputs to those generated by the Auburn PSS12. The PSS12 has been shipped to Auburn in order to determine the problem. Once this problem is solved, the algorithm can be tested in real time.

Task IV. Wichmann radar system modeling and signal processing

Work completed: Initial algorithm development work has focused on signal processing algorithms to automatically process the radar signals and differentiate between targets and clutter. Digital data was gathered at the JUXOCO site, and photographs of the oscilloscope output were obtained in the A. P. Hill mine lanes. Preliminary results with a limited data set collected with the BRTRC Wichmann antenna array indicate that mines can be successfully differentiated from clutter using GPR. The utility of statistical approaches for target detection is also illustrated via comparison to a standard energy detector. The results from the JUXOCO site should be viewed cautiously due to the limited amount of data available for analysis. However, the preliminary results demonstrate very good detection performance when a likelihood ratio is implemented, particularly when a clutter model is included. In addition, when data from the grass lanes that had been manually digitized was processed, the algorithm was successful at discriminating the mines for which it had been trained from non-mines.

The model has been completed and it's validity for modeling canonical targets has been verified. A paper describing this work has been submitted to NVESD/JUXOCO/BRTRC for their review. We are currently working on using the model to predict the signature of landmines, since they are more complicated targets. The first mine that is being modeled is the VS50, followed by the M19 and the VS2.2. Comparisons will be provided to both NIITEC and NVESD when this work is completed.

Task V. Multiple target modeling and verification

Work completed: This task was delayed until the above tasks were completed.